Evaluation of GLI reflectance and vegetation indices with MODIS products

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Abstract— Vegetation over land plays an important role to the carbon cycle, which influences global warming. It is necessary to measure vegetation amount accurately on global scale to understand the carbon cycle mechanism. The Japan Aerospace Exploration Agency (JAXA; former NASDA) has successfully launched a new Advanced Earth Orbiting Satellite (ADEOS-II) aboard an H-2A booster on December 14, 2002. The ADEOS-II satellite is focused on monitoring of global climate change on the Earth. Unfortunately, the operation of ADEOS-II satellite has stopped on October 24 of 2003, but very important VNIR/SWIR/MTIR data have been obtained in northern hemisphere for vegetation dynamics by GLI sensor. These data have enough capability to monitor the density and vigor of green vegetation. GLI data has high potential for vegetation monitoring, and it will contribute to the future satellite sensor. 23 channels are dedicated for land observations in the two spatial resolutions (1km/250m). MODIS sensor has also 1km/250m resolution and various land products, which include VIs. This paper shows the preliminary evaluation of GLI land products for vegetation monitoring using MODIS VIs product.

I. Introduction

The Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) concluded that an increasing body of observations gave a collective picture of a warming world and other changes in the climate system. Vegetation over land surfaces contains carbon that is released to atmosphere as carbon dioxide. Therefore, global vegetation monitoring is quite important for prediction of future global climate changes. The vegetation biophysical parameters should be sufficient accuracy to be used as an input of general circulation models (GCM).

Satellite remote sensing can provide the spatial and temporal coverage for global vegetation monitoring. Recent many studies use this technology as an attractive tool for global carbon researches. For example, NOAA/AVHRR, Terra/MODIS, and Aqua/MODIS have great contribution to monitor global environment. Nemani et al. (2003) shows that NPP was increased 6 percent over extensive regions of the Earth with the largest increase in tropical ecosystems using long-term satellite datasets.

The ADEOS-II satellite was launched successfully on December 14, 2002. GLI onboard the ADEOS-II satellite is an optical sensor developed by the Japan Aerospace Exploration Agency (JAXA; former NASDA) ,which is world's top class performance to monitor global environment of atmosphere, ocean, cryosphere,and land. Data obtained by GLI sensor should contribute to link to IPCC Assessment Process. GLI is a successor of Ocean Color and Temperature Scanner (OCTS) onboard ADEOS satellite with various advancements for further expansion of observations. GLI has 23 channels in visible and near-infrared region (VNIR), 6 channels in short wavelength infrared region (SWIR), and 7 channels in middle and thermal infrared. Spatial resolution of the sensor is 1 km at nadir excepts 6 channels in VNIR regions, which have 250 m resolutions designed for vegetation and cloud observations. Single mechanical scan covers 12 picture elements (12 km) along the forward direction and 1600 km along the cross-track. 23 channels are dedicated for land observations in the two spatial resolutions; channels 1, 5, 8, 13, 15, 17, 19, 24, 26, 27, 28, , 29, 30, 31, 34, 35, and 36 (1km ch.28 and ch.29 are resampled to 2km) are for 1 km resolution , and channels 20, 21, 22, 23, 28, and 29 are for 250 m resolution. Thus, GLI allows us to observe vegetation status in the two different resolutions simultaneously. The band positions and widths of these channels were decided based on reflectance spectra from various land objects. The observation region by mechanically scanning is 12 picture elements (12 km) to the forward direction and 1600 km in the cross-track direction.

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II. Objective

Many land users might use L1B data or higher level data. GLI higher level processed data are four kinds of products; those are PGCP (parameter of geometric corrected image), L2A_LC (TOA reflectance), L2AC_LC (reflectance after atmospheric correction), and VGI (NDVI and EVI). The objective of this study is to evaluate GLI higher level processing after level 1 and show the preliminary results.

III. GLI Land Higher Level Processing

GLI higher level processing is mainly precise geometric correction, 16-day composite, atmospheric correction, and vegetation index (NDVI and EVI).

The accuracy of geometric correction is dependent much on the accuracy of the satellite position and attitude. The GLI precise geometric correction algorithm enables to determine the precise satellite position and attitude using ground control points (GCPs). The rectification of original image is carried out using the results of the exterior orientation. The characteristics of this algorithm can determine precise satellite position and attitude utilizing GCPs ,which is extracted automatically. And it is able to determine precise satellite position and attitude based on photogrammetry. GTOPO30 is the digital elevation data used for 250m correction for terrain elevation.

After precise geometric correction processing, output value is TOA radiance derived from L1B. Cloud detection and screening algorithm produce cloud flags on a pixel basis. The composite algorithm produces geometrically corrected 16-day surface composites, which may select the best value pixel over a composite period, based on cloudiness and atmospheric contamination. The constraint view angle maximum value composite (CVMVC) technique is used to generate these composites. CVMVC algorithm on atmospherically uncorrected data are selected for GLI land algorithm (Cihlar et al., 1994a). Output value of this algorithm is TOA reflectance in VNIR and SWIR wavelength region,

$$\rho_{obs} = \frac{\pi L_{sat}}{F_0 \cos(\theta_s)}$$

where ρ_{obs} is GLI observed reflectance, $F_0[W/m^2/\mu m]$ is irradiance based on Thuiller 2002 (Thuiller et al., 2003), $L_{sat}[W/m^2/str/\mu m]$ is GLI observed radiance, and $\theta_s[rad]$ is solor zenith angle. The GLI Project adopted solar irradiances from Thuillier 2002. GLI calibration team calculate GLI-band solar irradiances that have been weight-integrated the Thuillier 2002 solar spectral irradiance by spectral responses of every GLI channels. The GLI spectral response is running averaged ± 2 samples (data interval is about 1nm) window to reduce a measurement noise, and both response and solar irradiance datasets are linearly interpolated to 0.1nm spectral resolution before the integration. Thuillier 2002 is new spectral irradiance data set including SOLSPEC observed data, which is the UV and visible solar spectrum acquired by spaceborne sensors flown during the ATLAS Space Shuttle missions (spectral resolution is 1nm-5nm, range 200nm-2500nm). In case of longer wavelength than 2500nm, MODTRAN4.0 IR solor irradiance is used.

GLI atmospheric correction for land is conducted for Rayleigh scattering and Ozone absorption. Rayleigh scattering and ozone absorption are corrected with the assistance of ancillary data NOAA/TOVS data set and GTOPO30. GLI observed reflectance at Top-Of-Atmosphere is described as the following equation:

$$\rho_{obs}(\tau_{O_3}, \tau_R, \theta_s, \theta_\nu, \varphi_{s-\nu}) =$$
$$T_{O_3}(\tau_{O_3}, \theta_s, \theta_\nu) \times$$
$$(\rho_R(\tau_R, \theta_s, \theta_\nu, \varphi_{s-\nu}) + \frac{T_{R\downarrow}(\tau_R, \theta_s)\rho_s T_{R\uparrow}(\tau_r, \theta_\nu)}{1 - S_R(\tau_R)\rho_s})$$

where ρ_{obs} is GLI observed reflectance derived from composite algorithm, T_{O_3} is ozone transmittance, ρ_R is path radiance, $T_{R\downarrow}$ is downward transmittance, $T_{R\uparrow}$ is upward transmittance, S_R is spherical albedo, and ρ_s is Rayliegh/Ozone corrected reflectance, which is output of this algorithm. The path radiance, upward and downward transmittance and spherical albedo were tabulated as functions of optical thickness of Rayleigh scattering (τ_R), view and illumination angles. Then, these four values will be retrieved based on the values of τ_R for each pixel at each land channel based on the pixel elevation, BPF, and STSG. τ_R relates to elevation through standard pressure and temperature (US62), which can be calculated with GTOPO30. And T_{O_3} can be derived from NOAA/TOVS data.

The vegetation indices (VI) have been used as an intermediate variable to quantify status and amount of vegetation from satellite images. Various VI products currently exist and more VI products are expected to be available simultaneously, the estimation of biophysical parameters through VI has to be compatible by various sensors to ensure continuity of global environmental simulation over generations. Therefore, NDVI should be land product for global land monitoring. The NDVI has been the most widely used index in global vegetation studies including phenological studies of vegetation growing season and so on. The NDVI is described as the following equations (Rouse et al., 1974);

$$NDVI = \frac{\rho_{NIR} - \rho_{RED}}{\rho_{NIR} + \rho_{RED}}$$

where ρ_{NIR} is reflectance in near infrared region, and ρ_{RED} is reflectance in visible red region (ρ_{obs} or ρ_s).

This index can reduce noise and uncertainty associated with instrument characteristics, topographical effect, and so on. On the other hand, this index also has disadvantages. This index saturates at the high biomass area, and has sensitivity to canopy backgrounds over open canopy conditions (Huete et al., 1997).

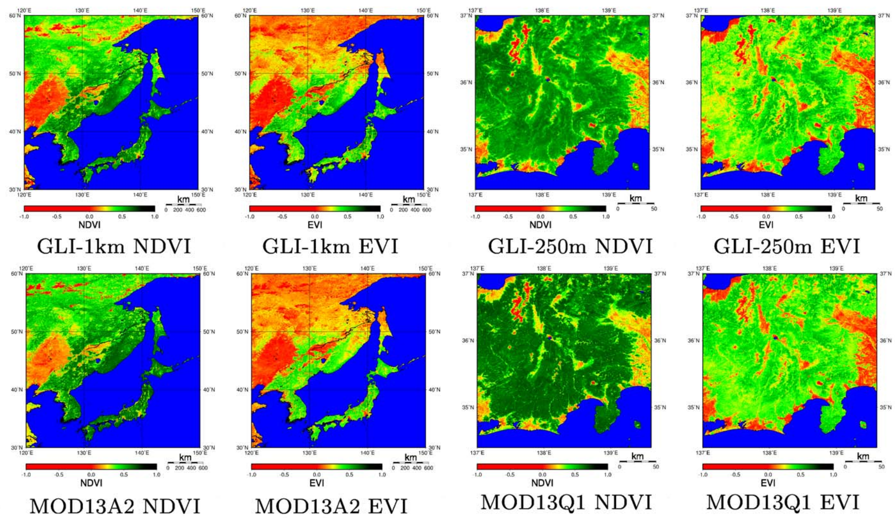

Fig. 1. GLI and MODIS VI product

GLI land team adopt another new index, an 'Enhanced Vegetation Index' (EVI) for increased sensitivity over a wider range of vegetation conditions, removal of soil background influences, and removal of residual atmospheric contamination effects, which is seen in the NDVI (Liu and Huete, 1995). The soil background adjustment is based on the soil adjusted vegetation index (SAVI) (Huete 1988). An atmospheric resistant term is derived from the atmospherically resistant vegetation index (ARVI) (Kaufman and Tanré,1992). The EVI equation shows as the following;

$$EVI = G \times \frac{\rho_{NIR} - \rho_{RED}}{L + \rho_{NIR} + C1 \times \rho_{RED} - C2 \times \rho_{BLUE}}$$

where L is the canopy background and snow correction caused by differential NIR and red radiant transfer (transmittance) through a canopy; and C1 and C2 are the coefficients of the aerosol 'resistance' term, which uses the blue channel (ρ_{BLUE};ρ_{obs} or ρ_s) to correct for aerosol effects in the red channel. Huete et al.(1997) shows that the currently used coefficients, G = 2.5; L = 1; C1 = 6; and C2 = 7.5, are fairly robust. Especially, aerosol variations are considerably reduced by the self-correcting combination of the red and blue channels as less prone to instrument noise compared with the AVHRR. GLI 1km bands are much narrower than the GLI 250m bands, and provide increased chlorophyll sensitivity (channel 13) and avoids water vapor absorption (channel 19). The blue channel provides aerosol resistance in the EVI.

IV. Quality of GLI land higher products

The geometric accuracy by system correction just after the launch was a few kilometers on the ground. If a few GCPs are acquired for 1 scene (precise geometric correction), the geometric accuracy of 1km/250m image is less than 1 pixel (Hashimoto et al., 2004). Band-to-band registration errors were recognised in proportional to arrangement of detectors on the focal plane at initial check out, however, this has been also improved, which become within 0.5 pixel.

The saturation level for land is almost satisfied with maximum radiance of specification. In case of GLI 1km land channel, Ch. 5,8,13,15,19 may be saturated in high bright cloud and ice cloud. In land area, the saturation is not confirmed. In case of GLI 250m channel, Ch.22 are sometimes saturated on the part of desert bright area as estimated by the pre-launch analysis. And Ch.23 is rarely saturated like 1km land channels without the extreme bright cloud. The DN of VNIR2 (land channel Ch.13,19,22,23) turns down partly in the range exceeding the saturation level (over saturation). They will not be critical problems in the unsaturated radiance range. The L1B DN of Ch.30 (3.7 μ m) frequently becomes zero in low-temperature (<240K) areas, however this will be occurred at the top of high-altitude clouds and in polar regions in the nighttime (Murakami et al., 2003).

Ch.19 NIR channel is narrow-band, and it has been designed to avoid to water vapour absorption. Therefore, water vapour effects does not affect to GLI 1km NDVI/EVI. GLI 250m NDVI/EVI has capability of influence of water vapour effects, because band-width of GLI 250m channels are wider than 1km channels. GLI 1km NDVI/EVI might be affected by aerosol over land, and GLI 250m NDVI/EVI could be affected by both of aerosol and water vapour. EVI coefficients may be able to be adjusted for GLI, because GLI blue channel position is different from MODIS.

V. Intercomparison of GLI and MODIS VI products

MODIS/Terra/Aqua land higher level products also includes NDVI/EVI. The inputs of MODIS VI products depend on daily MODIS land surface reflectance (MOD09G). GLI atmospheric correction algorithm is conducted for rayleigh scattering and ozone absorption. On the other

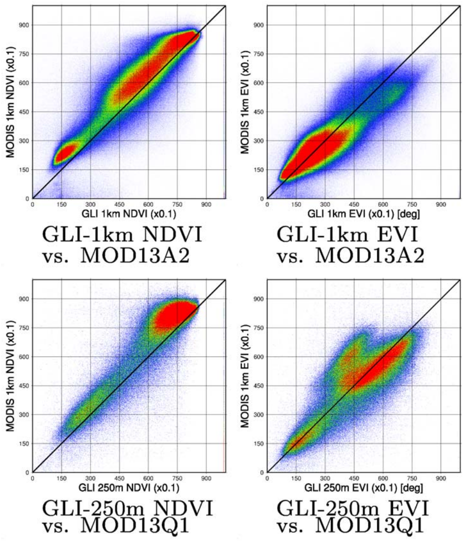

Fig. 2. GLI vs. MODIS VI product

hand, MOD09 is conducted by rayleigh scattering, ozone absorption, aerosol effects, water vapour absorption, other trace gases absorption, adjacency effect, and so on. GLI VI products are able to compare with MOD13A2 and MOD13Q1.

Fig.1 shows atmospherically corrected GLI and MODIS 1km/250m VIs images. Both of GLI and MODIS composite data were generated from atmospherically corrected reflectance, which were obtained from May 25 to Jun. 9, 2003. GLI NDVI/EVI values seem very similar to MODIS NDVI/EVI. Fig.2 shows scatterplot of atmospherically corrected GLI 1km/250m 16-day NDVI/EVI composite against MODIS 1km/250m 16-day NDVI/EVI composite. This indicates that GLI 1km/250m NDVI is slightly lower than MODIS 1km/250m NDVI. On the other hand, GLI 1km EVI is slightly higher than MODIS 1km EVI. But GLI-MODIS 250m EVI has better correlation than GLI-MODIS 1km EVI. This looks the capability of dependancy on EVI coefficients.

VI. Conclusion

This study shows the initial evaluation of GLI land higher level processing and the preliminary results using MODIS VI products. The following items can be concluded.

- The accuracy of GLI 1km/250m precise geometric correction is less than 1pixel.
- It is needed to evaluate GLI 1km/250m higher level products. Validation of GLI 1km/250m products should be conducted by using other sensors (e.g. MODIS) and ground-based validation data.
- GLI 250m channels can be affected by atmospheric effects more effectively than 1km channels.
- Atmospherically corrected 1km reflectance and VIs should be considered to aerosol effect.
- Atmospherically corrected 250m reflectance and VIs should be also considered to both of aerosol and water vapour effects.
- GLI 1km/250m NDVI values are slightly lower than MODIS 1km/250m NDVI.
- GLI 1km EVI values are slightly higher than MODIS 1km EVI.
- GLI-MODIS 250m EVI has better correlation than GLI-MODIS 1km EVI.

In future, GLI land higher level algorithm should include correction for aerosol over land. 250m channels are expected to be affected by water vapour and aerosol, because these channels are broader band than 1km channels. Therefore, 250m algorithm may have to be different from 1km algorithm.

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